박막 두께 및 형상 측정을 위한 분산형 위상천이 간섭계

Spectrally Resolved Phase Shifting Interferometry for Film Thickness and Surface Profiling

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1. Introduction

Many applications of semi conductor industry transparent film like SiO_2 are deposited whose thickness need to be determined. One technique to measure film thickness is by scanning white light interferometry[1]. The reference surface of the interferometer is scanned vertically to acquire white light interferogram. A large number of frames were recorded and processed to get the three dimensional profile and thickness of the sample. Another technique using white light is spectrally resolved white light interferometry[2]. Each dispersed wavelength carries information about the test system. In this technique a white light interferogram is dispersed by a spectrometer and projected on a CCD camera. It gives a two dimensional profile and to get three dimensional profile the test sample is scanned laterally. Both the above techniques were based on the determination of phase for different wavelengths of the white light source. The former technique use Fourier Transform and the later physically separate the wavelength to extract the require information.

Reflectometry is long available technique for measurement of the film thickness[3, 4]. It measures reflectance for different wavelength to calculate thickness. This technique can only determine the film thickness and it is a point detection technique. Recently, reflectometry and spectrally resolved white light interferometry were combined for measurement of film thickness and surface profile[5]. It used a two step procedure. Initially the film thickness is determined by recording the reflectance from the sample. In second step the test sample is allowed to interfere with a reference surface and Fourier Transform was applied to the spectral interference to determine the surface profile. A large numbers of fringes (carrier fringe) are require in the field of view to apply Fourier transform. A Linnik interferometer which is sensitive to the environmental fluctuation should be used to get large number of fringes in spectral domain. In this paper we propose to use a Michelson objective with the phase shifting technique to determine the film thickness and surface profile of the sample. The most important advantage of the proposed technique is to get rid of the carrier fringe.

2. Principle and Experimental Setup

Figure 1 shows the schematic of the experimental setup. The test surface is observed through a Michelson–type Interferometric microscope objective (5x). The white light reflected from the test and reference surface were interfered to produce the interference pattern. The white-light interferogram of the surface is passed through the spectroscope. The spectroscope selects a line on the surface. The output of the spectroscope is received on a CCD camera. To implement the phase shift the objective mount is fitted with a PZT. The control voltage to shift the PZT for phase shifting is produced by a digital to analog card (NI DAQ). The camera (Sony XC-ST70) gives a 8 bit digital output. The setup consists of a shutter in the reference arm of the interferometric objective whose function is describe below.

The experiment was performed in two steps. First the film thickness was determined by reflectometry mode and then the surface profile is calculated in spectrally resolved white light interferometry (SRWLI) mode.

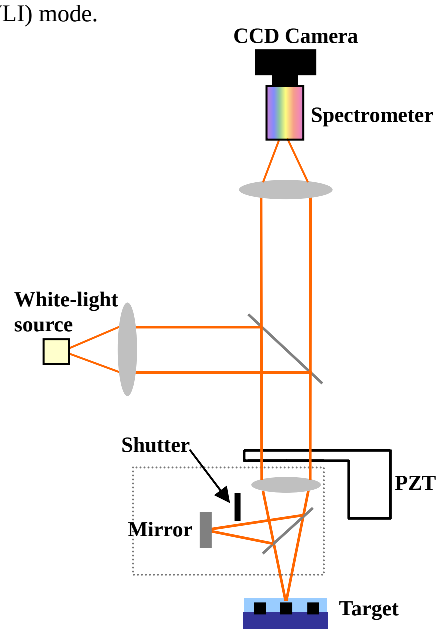

Fig. 1: Experimental setup

2.1. Reflectrometry mode (shutter 'on')

In this mode the shutter is 'on' so that there is no light reflected from the reference surface. The light reflected from the test sample suffers multiple reflections between the top and bottom surface of the film and projected on the CCD camera. The reflection coefficient of the surface, R for normal incident is given by the relation

$$R = \frac{r_{01} + r_{12}\exp(-4i\pi\sigma N d)}{1 + r_{01}r_{12}\exp(-4i\pi\sigma N d)} \tag{1}$$

where r_{01} and r_{12} represent the Fresnel reflection coefficients of the top and bottom surfaces of the film. N, d and $\sigma(=1/\lambda)$ are the refractive index, film thickness and the wavenumber respectively. The parameter R is a complex quantity and the phase of the reflected beam is given as,

$$\psi = \arctan(\mathrm{imag}(R)/\mathrm{real}(R)) \tag{2}$$

where imag(x) and real(x) denotes the imaginary and real part of x respectively. It follows that once the Fresnel reflection coefficients and the refractive index in the thin film are known, the phase of the reflected beam can be obtained from a function that involves only the wavenumber σ and the film thickness d. To determine the film thickness d at any point, we use the values of the measure reflectance $\Re_{measured}(\sigma)$. We can define an error function

$$\eta(d) = \sum_{\sigma_c - \Delta\sigma/2}^{\sigma_c + \Delta\sigma/2} \left[\Re_{model}(d) - \Re_{measured}(\sigma)\right]^2 \tag{3}$$

where σ_c and $\Delta\sigma$ are, respectively, the central wavenumber and the bandwidth of the white-light source. The unknown film thickness d in this error function is regarded as independent variables and is determined, using a least-squares algorithm, so as to minimize this error function. $\Re_{model}$ is the model reflectance which corresponds to minimum value of the error function $\eta(d)$.

2.2. SRWLI for measurement of surface profile (shutter ‘off’)

In this mode the shutter is off so that the light reflected from the reference surface is allow to interfere with the test surface beam. The total spectral phase observed by the CCD camera is given by[1,2]

$$\phi(z, d, \sigma) = 4\pi\sigma z + \psi(\sigma, d) \tag{4}$$

where z represents the distance from the reference plane to the top surface of the transparent film. The first term on the right-hand side of Eq. (4), which is the phase term due to the air gap, is a linear function of σ which gives the information about the surface variation. The second term of Eq. (4), ψ can be determine by the Eq. (2) discussed in the previous sub section after knowing the thickness of the film. The phase ϕ can be determined by the phase shifting technique. We used the eight step algorithm as given by[6]

$$\tan\phi = \frac{-I_1 - 5I_2 + 11I_3 + 15I_4 - 15I_5 - 11I_6 + 5I_7 + I_8}{I_1 - 5I_2 - 11I_3 + 15I_4 + 15I_5 - 11I_6 - 5I_7 + I_8} \tag{5}$$

where I_1, I_2…… I_8 are the phase shifted interferogram. From Eq. (4) it can be seen that the slope of $(\phi-\Psi)$ vs. σ is $4\pi z$. So once we know the phase ϕ we can easily determine the value of z by the knowledge of the thickness of the film.

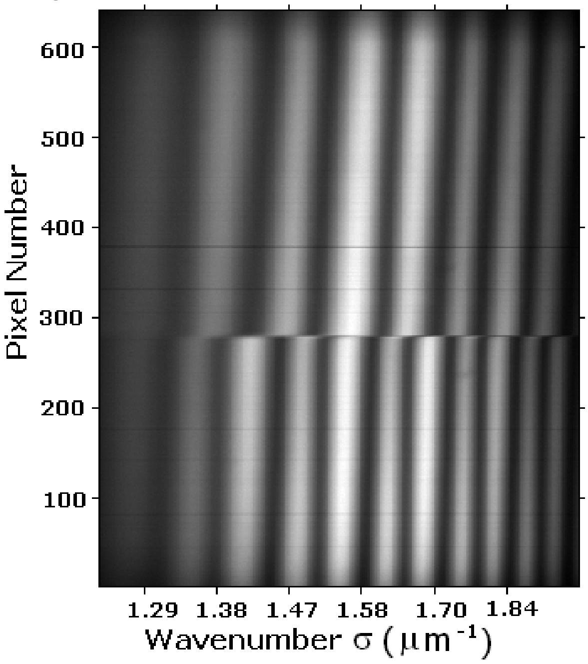

Fig. 2: Interferogram recorded by the CCD camera when the shutter is ‘off’

3. Experimental results

We carry out an experiment with a silica step on which SiO_2 is deposited. The film thickness is determined by reflectrometry as describe in section 2.1. To determine the surface variation, SRWLI mode is activated by shutter ‘off’. Figure 2 shows the interferogram recorded by the CCD camera when the shutter is off (SRWLI mode). Such eight phase shifted interferogram were recorded. Using Eq. (5) the phase ϕ was calculated and shown in Fig. 3. Due to the nature of the arctangent calculation, Eq.(5) yields wrapped phase ϕ. Since phase ϕ is continuous we unwrapped the phase from Fig. 3. Since we know the film thickness by the reflectrometry mode we can determine the phase Ψ from Eq. (2). After knowing the phase ϕ and Ψ we can easily plot the $(\phi-\Psi)$ vs. σ. Linear fit to this line gives the value of z. Once we know the value of z and d we can have the plot of the top and bottom surface of the film. Figure 4 shows the profile of the top and the bottom surface of the SiO_2 film.

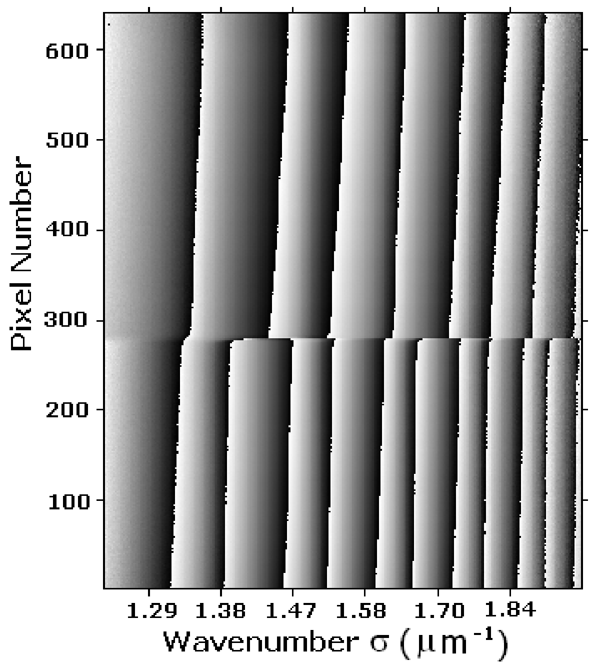

Fig. 3: Phase map calculated using Eq. (5)

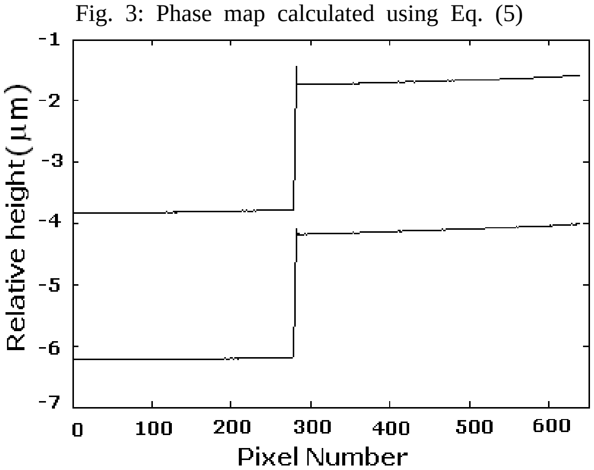

Fig. 4: Profile of the top and bottom surface of the sample

4. Conclusion

We successfully implemented reflectrometry with spectrally resolved white light interferometry for determination of film thickness and surface profile.

Reference

1. S-W. Kim and G. H. Kim, “Thickness profile measurement of transparent thin-film layers by white-light scanning interferometry,” Appl. Opt. **38**, 5968-5973 (1999).
2. S. K. Debnath, M. P. Kothiyal, J. Schmidt, and P. Hariharan, “Spectrally resolved white light phase shifting interference microscopy for thickness–profile measurements of transparent thin film layers on patterned substrates ” Opt. Express, **14**, 4662-4667 (2006).
3. H. G. Tompkins and W. A. McGahan, *Spectroscopic Ellipsometry and Reflectometry: A User’s Guide* (Wiley, New York, 1999).
4. A. Rosencwaig, J. Opsal, D. L. Willenborg, S. M. Kelso, and J. T. Fanton, Appl. Phys. Lett. **60**, 1301 (1992).
5. Y. S. Ghim and S. -W. Kim, “Fast, precise, tomographic measurements of thin films”, Appl. Phys. Lett. **91**, 091903 (2007).
6. J. Schmit and K. Creath, “Window function influence on phase error in phase-shifting algorithms,” Appl. Opt. **35**, 5642-5649 (1996).